Engineering Sciences
Microscale Science

FemtoNewton-Scale Colloidal Force Measurement using Optical Trapping

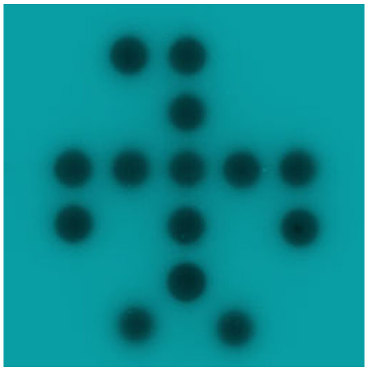

Figure 1: Laser tweezers optical trapping is used here to manipulate silica microparticles into a Sandia thunderbird.

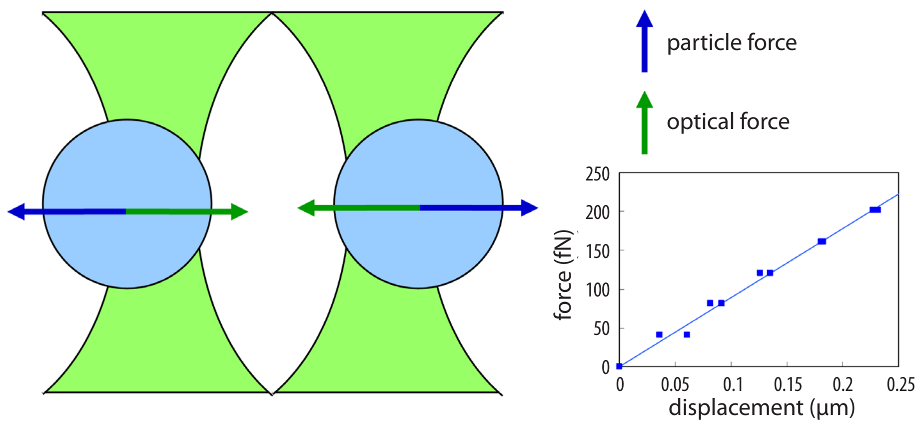

Figure 2: Diagram of the direct force technique to measure forces between colloidal particles. If a particle feels a repulsive force from a nearby particle, it will be pushed out of the center of the optical trap. By looking at the equilibrium position of the particle, we can determine the colloidal force from the known restoring optical force.

The ability to measure tiny forces between particles has widespread applications in nanotechnology and biology

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Optical manipulation of small objects using focused laser light was pioneered by Arthur Ashkin, and has found wide-spread application to both biological and physical sciences. By harnessing light's momentum, objects from neutral atoms to living cells can be trapped in three dimensions (Figure 1). Laser-based optical trapping has also been used to measure weak forces between small charged microparticles such as colloids. At Sandia, the extremely weak femtoNewton (fN, 10^{-15} N) forces between two colloidal particles have been measured by using two independent implementations of optical trapping for the first time.

The first technique, "direct force," relies on knowing the force required to hold the particle in the center of the optical trap. Once this restoring force is calibrated, one can measure other external forces applied to a trapped particle by monitoring its position relative to the center of the optical trap. As shown in Figure 2, when two trapped particles are brought close to each other, the displacement from the trap center for each particle increases proportionally to the interaction force. The full range of inter-particle forces is determined by gradually moving the two trapped particles closer together.

The second technique, "blinking laser tweezers," takes advantage of the natural thermal diffusion of colloidal particles. Two particles are held near each other and then the optical traps are turned off. The particles then move due to random Brownian motion and any other applied forces. By repeatedly catching and releasing a pair of particles, one can gather physical statistics of many particle trajectories (Figure 3). Statistical analysis is used to determine drift velocities, diffusion coefficients, and ultimately colloidal forces as a function of the center-center separation of the particles. The optical traps allow the particles to come into energetically unfavorable separations which are frequently found in flows of concentrated colloids. Also, since the measurements are made while the lasers are turned off, there is no risk of optical forces or induced dipoles affecting the measured forces.

Both approaches were used independently to examine the forces in a model system of polystyrene microparticles suspended in hexadecane with 1mM AOT (dioctyl sodium sulfonsuccinate, a surfactant used as a charge control agent). As shown in Figure 4, the forces are measured, using both direct force and blinking techniques, as a function of the distance between two particle surfaces. At large separations, their electrostatic repulsion is completely screened by the surrounding fluid and there is no measurable force. As the particles approach each other, the repulsive electrostatic force between them increases rapidly in a form well represented by Derjaguin-Landau-Verwey-Overbeek (DLVO) theory (black line). The two methods agree quantitatively and have a force resolution of 30 fN.

Currently, these measurements of weak interaction forces are enabling predictive simulations of nanoparticle dispersion flow and stability for Sandia's Nanoparticle Flow Consortium. Optical manipulation is also being used to build novel particle structures with potentially unique optical properties. Future applications of the optical trapping methods include force measurements in biological systems, such as those occurring between cells or liposomes, in to order to understand their interaction with surfaces and each other as well as conditions required for membrane fusion.

References:

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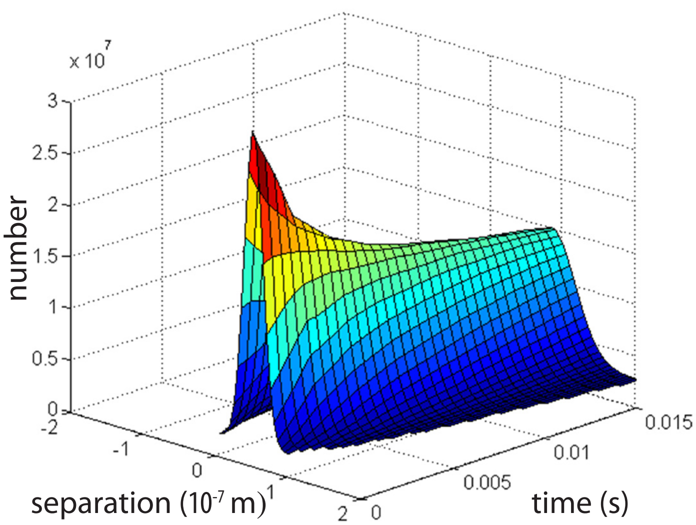

Figure 3: Blinking laser tweezers results showing histograms of particle separation as a function of time. As time passes after the optical traps are turned off, the distributions broaden as the particles diffuse around due to random Brownian motion. The central peak of the distributions also shifts to larger separations due to electrostatic repulsion. The particle diffusivity and mean velocity are used to calculate the force between the particles.

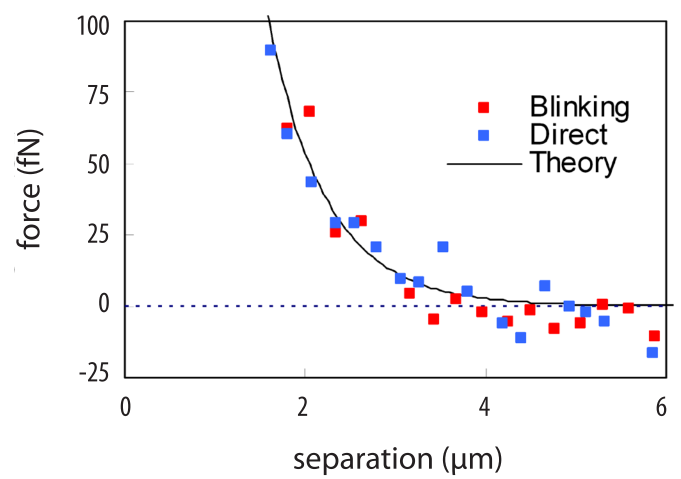

Figure 4: Measured interparticle force as a function of particle separation between two polystyrene particles in a hexadecane–AOT solution. The comparison is quantitative and well-represented by DLVO theory.

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